Our Journey through the Solar System
50 Years of Space Exploration

Denver Museum of Nature and Science
The Planets and their Spacecraft

Mercury
Venus
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto (Almost a Planet)

Saturn back light by Sun - Photo Courtesy NASA/JPL
Missions to Mercury

• Mariner 10
  – Launched 3 Nov 1973 arrived 29 Mar 1974 7 instruments including TV
  – First to use Venus gravity assist and “solar sail” when the
  – First Flyby, ended March 1975 after 3 flybys
  – Magnetic field, greater mass indicated an iron core which makes up 75 percent of the entire planet. Mapped ½ planet, sent over 8000 images
Missions to Mercury

- **Messenger**
  - Launched 3 Aug 2004, ~7 yr trip with all the flybys and gravity assists
  - Arrived 18 Mar 2011 after 3 flybys, mission ended 4/30/15 or 8.5 “Mercury days”
  - 1st to Orbit the Planet, Map the surface, Magnetosphere far different than discovered by Mariner 10, volcanic & past evidence for hot lava flows, magnetic field - active core dynamo that is ~ 85% of the radius, surface is dominated by minerals high in magnesium & enriched in sulfur; Water Ice

Photo Courtesy NASA
Early US & USSR Missions to Venus

- **Mariner 2** first to visit Venus – Flyby Mission
  - Launched 27 Aug 1962, Measured solar wind and solar flare particles, Measured cool clouds and hot surface, retrograde rotation, ended 1963

- **Venera 4, 5 & 6** (‘67-’69) First to sample the Atmosphere from another planet

- **Venera 7 & 8** first to return data from surface of a planet
  - Launched Aug 1970, First S/C Design to Survive the Environment, Parachute failed, but survived 23 mins on the surface
Early US & USSR Missions to Venus

- Venera 9 & 10 Orbiter/Lander; returned first photos from another planet
- Landers Venera 11 & 12 (‘78), 13 & 14 (‘82) & Orbiters Venera 15 & 16 (‘83)
- Vega 1 & 2 (‘85) were combined orbiter, lander and Halley Comet Flybys
- Total USSR, 10 landers, 6 Orbiters, 3 atmospheric probes
What We Saw on the Surface of Venus

- **Venera 9 & 10, First Photos from another Planet (Above, 22 & 25 Oct 1975)**
  - Venera 9 lasted 53 min
  - Venera 10 lasted 65 min

- **Venera 13 & 14, First Color Photo from Venus (5 May 1982)**
  - Venera 13 lasted 127 min
  - Venera 14 lasted 57 min

- **More Successful Landers than on Mars**

Photo Courtesy NASA
Orbiter Missions to Venus

- **Pioneer Venus**
  - Launched the Orbiter 20 May 1978 and the Probes 8 Aug’78
  - Detailed Atmosphere study & Radar Map, orbited for 14 yrs (1992)
  - A Probe transmitted from surface for 67.5 min

- **Magellan**
  - Launched May 4, 1989 on Space Shuttle, ended Oct 1994
  - Radar could “see” through clouds, Mapped 98% of planet
  - Lava Flows, maybe active, mapped surface through clouds

- **Venus Express (ESA)**
  - Designed from Mars Express and Rosetta spare parts
  - Measured the 1st global surface temperature distribution

- **Other Flybys** – Mariner 5 & 10
- **Gravity Assist** New Horizons, Cassini & Galileo
- **More Missions** than any other planet

Photo Courtesy NASA
What We Learned at Venus

- **Pancake volcanoes** (Magellan radar & Venera 13 color). 750 m high, formed by extrusion of viscous lava.
- **Pioneer Venus & Venus Express, 32 yrs of SO$_2$ evidence for volcanic activity or variation of atmosphere?**
- **Idunn Mons Volcano**, 2.5 km (Magellan radar & Venus Express thermal image)
  - Radar – Bright = rough, dark = smooth, Red-Orange Warm
- **Maxwell Montes**, highest mountains on Venus, 11 km. Cleopatra crater (105 km) Center.
Missions to Mars – Past Orbiters

• Mariner 9 was first spacecraft to orbit another planet
  – Launched 30 May 1971 and arrived 14 Nov 1971
  – Global mapping, returned 7329 images, ended Oct 27 1972
  – 1st to see large volcanoes and canyons, paved way for Viking

• USSR Mars 2 & 3, Launched May 1971, arrived 27 Nov 1971
  – Lasted 9 months, Orbiters sent 60 images
  – Both landers failed (Mars 3 lasted 20 s), along with small rover

• Viking 1 & 2 Orbiters
  – Sent back 51,539 images of 97% of surface

• Mars Global Surveyor
  – Launched 7 Nov 1996, arrived 11 Sept 1997, ended 2 Nov 2006; lasted 9 yrs
  – Mapped surface, discovered evidence ground water, 3D image of north pole

Photos Courtesy NASA
Missions to Mars – Current Orbiters

• Mars Odyssey
  – Thermal imaging, Gamma ray & neutron spectrometer and the high-energy neutron detector, discovered frozen ground water, confirmed by Phoenix

• Mars Express (ESA)
  – Launched 2 Jun 03, arrived 24 Dec 03, still working and relaying rover data
  – First radar instrument, showed underground water-ice deposits, found CH₄

• Mars Reconnaissance Orbiter
  – Launched 12 Aug 2005, arrived 10 Mar 2006, still operational; hi-rate data relay
  – >100 terabits data, hi res photos, action of water on and near the surface

• Mars Atmosphere and Volatile Evolution, MAVEN
  – launched Nov. 18, 2013, arrived 21 Sept, 2014
  – Studying the evolution of the atmosphere and relaying data

• Mars Orbiter Mission MOM, India’s 1st launch of a Mars orbiter
  – launched Nov. 2013, arrived 23 Sept, 2014
  – Also studying the atmosphere
Missions to Mars – Past Landers

• **Viking 1 & 2**
  - Landed 20 July 1976, mission ended Nov 1982
  - Weather station, imager, gas chromatograph mass spec, x-ray fluorescence, biological laboratory - False Positive for life, first surface photos, 4500 combined, robotic arm to scope samples

• **Pathfinder Lander & Rover**
  - 1st spacecraft to bounce on another planet, 1st wheeled rover on a planet

• **Phoenix Lander**,
  - Thermal and Evolved-Gas Analyzer, Atomic Microscope, Electrochemistry, Weather Station
  - Detected Perchlorate in soil, falling snow, 25,000 images

Photos Courtesy NASA
Mars Landers and Rovers

Drawing Courtesy NASA
Pathfinder-Sojourner

Photos Courtesy NASA/JPL
Missions to Mars – Current Landers

- **Mars Exploration Rovers (2)**
  - Dust devils, modern water/ice, may have had a habitable environment billions of years ago, evidence of ancient acidic lakes

- **Curiosity Rover**
  - Geology lab, ChemCam, rock-vaporizing laser, X-ray diffraction, weather station
  - Mar 2013 NASA announced that it discovered evidence Mars could have supported microbial life billions of years ago.
Curiosity Rover

Photo Courtesy NASA/JPL
dark, narrow lines seen on Martian slopes hint that saltwater could be running down them every spring.
Planetary Gravity Assist (Flybys) Gave Voyager a Big Boost for the Grand Tour

Titan IIIE Centaur Voyager - NASA

Jupiter Io - Courtesy NASA

Plots Photo Courtesy NASA/JPL

www.jpl.nasa.gov/basics
Missions to Jupiter

• Pioneer 10, first to visit Jupiter & Pioneer 11
  – Launched 2 March Arrived 4 Dec ’73 (closest)
  – First to Asteroid belts & Jupiter, Nearly Fried by Ions Magnetic Field.

• Voyager 1 & 2
  – Launched V-2 Aug/V-1 Sept 1977, Arrived V-1 Mar, V-2 July 1979
  – Discovered 22 new satellites, more next page

• Galileo
  – Launched 1989 Arrived Dec 1995
  – First to Orbit & send a probe to Jupiter
  – HGA failed, LGA gave 70% scientific return
  – 14 yr mission, 6 yrs orbital, crashed into Jupiter

• Juno
  – Launched 5 Aug 2011, will arrive at Jupiter Jul 2016
  – Earth Flyby Oct 2013, 1st to use Solar Power at Jupiter
What We Learned at Jupiter

- **Pioneer 10 & 11**
  - Strong Magnetic fields and radiation by Pioneer
  - Pioneer data - scientists identified plasma in Jupiter’s magnetic field
  - Pioneer obtained photos of Callisto, Ganymede, and Europa (but not Io)
  - Pioneer 10 last contacted Jan 2003
  - To talk to it, NASA used a 1970’s IBM card computer

- **Voyager 1 & 2**
  - Rings discovered by Voyager
  - Europa found to be cover by ice
  - Active Volcanos on Io, only other body known
    - Discovered by Navigation image by Linda Morabito
  - Auroral zones were discovered by Voyager

- **Galileo**
  - Ida Moon (Dactyl), the first moon orbiting an asteroid.
  - Comet Shoemaker-Levy 9’s impact Jupiter
  - Photos of realtime (~400) Io volcano, send SO$_2$ into space
  - Helium same as in the Sun
  - Liquid salt water ocean under Europa's 100 km thick Ice.
  - Organic compounds on Callisto, Ganymede, Europa, and Io.
  - Ganymede's intrinsic magnetic field (1$^{st}$ for a moon)
Jupiter Moon Europa (Galileo)

Jupiter Moon Io Eruption (Voyager)

Jupiter Aurora (Hubble)

Photo Courtesy NASA/JPL
Missions to Saturn

• Pioneer 11 First to visit Saturn
  – Launched 4/5/73, arrived 1 Sept 1979
  – Visited Jupiter, Saturn, outer solar system
  – Pioneer 11 Last contact in 1995, antenna lost light-sight

• Voyager 1 & 2
  – Arrived: V-1, Nov 1980; V-2, Aug 1981
  – Voyager 1 is now over 12 billion miles from the Sun after 38 yrs

• Cassini/Huygens – A current Orbiter after over 11 yrs
  – First Orbiter of Saturn & Probe to land on Titan
  – Launched 15 Oct 1997, Arrived 1 July 2004
  – Huygens Probe landed on Titan 14 Jan 2005
Cassini Got a Boost from Venus, Earth & Jupiter

In Orbit around Saturn

Jupiter Fly-by

Earth Fly-by

1st Venus Fly-by

2nd Venus Fly-by

www.jpl.nasa.gov/basics

Titan IVB Centaur Cassini - NASA

Ethane lake on Titan – Courtesy NASA

Plots Photo Courtesy NASA/JPL
What We Learned at Saturn

**Pioneer**
- Pioneer 11 was the first human-made object to fly past Saturn and also returned the first pictures of the polar regions of Jupiter.
- "F" ring, a new satellite 200 kilometers in diameter. -180°C, data suggested that the planet made of liquid hydrogen.
- Jupiter's enormous magnetic tail extended to Saturn

**Voyager**
- Discover 3 new moons, Auroral zones, Storms, Titan N2 & Methane
- Voyager 1 visited Titan, photographed, Mimas, Enceladus, Tethys, Dione, and Rhea. The moons appeared to be largely composed of water ice.
- Rings were found to contain spokes in the B-ring and a braided structure in the F-ring.

**Cassini** - Among the most surprising discoveries were:
- Methane lakes on Titan
- Ice geysers erupting on Enceladus feeding E Ring and the dynamic effects of other moons on Saturn's rings.
- Ocean similar to Earth’s under Enceladus Ice surface
- Observations of Titan have given scientists a glimpse of what our home planet might have been like before life evolved.
The first images released to the world of Titan from the Huygens probe during the descent
• The First Pictures from the most distance surface we have landed on to date.

Photos courtesy ESA/NASA/
University of Arizona
Cassini’s many flyby of Titan discovered Lakes

Methane/Ethane lake on Titan – Courtesy NASA
NASA Cassini Discoveries
Mission to Uranus

- **Voyager 2 - Arrived Jan 1986**
  - Voyager 2 was sent to Uranus and Neptune after the successful encounter of Saturn’s moon Titan by Voyager 1
  - Discovered 10 new moons
  - Discovered a magnetic field which is offset from the side-ways planet rotational axes, suggesting their source are significantly different from other magnetospheres.
  - Two new rings were discovered at Uranus
Mission to Neptune

- **Voyager 2 - Arrived Aug 1989**
- **Discoveries**
  - Neptune, large storms (Great Dark Spot), Auroral zones and magnetospheres highly inclined and offset from the planets' rotational axes, suggesting the source is significantly different from other magnetospheres.
  - Discovered 5 new moons
  - Neptune's rings, originally thought to be only ring arcs, were found to be complete, albeit composed of fine material.
  - The strongest winds on any planet, 1,100 km an hour, and blow opposite to the rotation of the planet. (flew 4950 km above clouds)
  - Moon Triton has active geyser-like eruptions of nitrogen gas and dark dust particles, possible ocean of LN2 under SN2 layer.
  - Triton's retrograde orbit indicates it may be a captured object.
  - Triton's thin atmosphere extends 500 miles, Nitrogen ice particles and pressure 1/70,000th of that on Earth.
  - Triton's is -391 F, coldest body in the solar system.
- **Voyager 2 is now more that twice as far from the Sun as Pluto (over 10 billion mi) - could transmit until 2025, well into interstellar space.**
Mission to Pluto
Mission to Pluto

- Pluto Flyby was a Voyager option but would miss Saturn’s rings and Titan
- New Horizons is the First Mission to Pluto
  - Launched Jan 19, 2006, arrived Pluto/Charon: July 14, 2015
  - Fastest SC to leave Earth, passed Moon in 9 hrs, reached Jupiter in 13 months
  - Flyby within 8000 mi, 4.5 hr transmit time, take 3 months to get all data to Earth

Photos/Drawings Courtesy NASA/JPL
Probes Leaving the Solar System

Outer Solar System Probes
Pioneer 10: 3 March 1972
Pioneer 11: 6 April, 1973
Voyager 2: 20 August 1977
Voyager I: 5 September 1977
Voyager’s Interstellar Mission (VIM)

- Voyager 1 and 2 collected data with the various fields and particles experiments and the ultraviolet spectrometer collecting data nearly continuously during the interplanetary cruise phases of the mission.
- Voyager 1 is in Interstellar Space (2012)
- Voyager 2 is in the Heliosheath, the Sun's solar wind is slowed by the interstellar gas.
- Voyagers have passed the Termination Shock (Dec 2004 & Aug 2007)
- Current round trip signals are 30 lhr (2) and 36 lhr (1) from Earth.
- The exploration goal of VIM and could transmit until 2023.

Table 1-1. Spacecraft lifetime estimates in calendar years.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Voyager 1</th>
<th>Voyager 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical power</td>
<td>2023</td>
<td>2023</td>
</tr>
<tr>
<td>Telemetry link capability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7200 bps, 70-/34-m HEF array</td>
<td>1994</td>
<td>1998</td>
</tr>
<tr>
<td>1400 bps, 70-m antenna</td>
<td>2007</td>
<td>2011</td>
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<tr>
<td>600 bps, 70-m antenna</td>
<td>2026</td>
<td>2030</td>
</tr>
<tr>
<td>600 bps, 34-m HEF antenna</td>
<td>2003</td>
<td>2007</td>
</tr>
<tr>
<td>160 bps, 34-m HEF antenna</td>
<td>2024</td>
<td>2029</td>
</tr>
<tr>
<td>40 bps, 34-m HEF antenna</td>
<td>2050</td>
<td>2057</td>
</tr>
<tr>
<td>Hydrazine for attitude control</td>
<td>2040</td>
<td>2048</td>
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</tbody>
</table>

\[a\] High efficiency.
Conclusion

Pioneer, Mariner, Venera, Voyager, Viking, Galileo, Cassini, Phoenix, Opportunity, Curiosity and New Horizons with cameras that extended our eyes to the all the planets, pictures that brought a new sense of wonderment, and discoveries that brought once-distant worlds to now familiar and unforgettable places.

Messenger - Portrait of the Solar System from the Inside, Courtesy NASA
Summary of A few Facts About Our Journey

- First planet we visited, Venus – Mariner 2 Flyby Dec 1962
- First planet’s atmosphere we sampled, Venus – Venera 4, Oct 18th 1967
- First planet we received data from the surface, Venus – Venera 7, Dec 15th 1970
- First photos from another planet, Venus – Venera 9, Oct 22nd 1975
- Most landings on another planet, Venus – 10 landers (USSR) plus 1 if you count Pioneer Venus small probe.
- First planet with an orbiter, Mars – Mariner 9, Nov 14th 1971
- Longest time on another planet’s surface, Mars – Opportunity Rover, 11 years and 3 months
- Farthest body we visited, Moon Titan 14 Jan 2005
- Planet visited the most, Venus, 21 times
- Total number of Spacecraft that have visited all 8* planets, 49

* Counting Pluto
The Probes that have Visited Planets (49)

- Count individual Spacecraft based on primary mission to a planet
  - Flyby of another Planet on their way to the primary mission are not counted
  - Grand Tour Probes are counted once by Multiple Planets (i.e. Voyager 2 counted with Jupiter, Saturn, Uranus and Neptune; Pioneer 11 Jupiter & Saturn)
- Separate Spacecraft are Defined as a Separate Launch from earth.
  - Spacecraft with multiple parts, i.e. lander and orbiter, that are launched together are counted as 1
- Mercury (2), Mariner 10, Messenger
- Venus (21), Mariner 2 & 5, Venera 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 & 16, Pioneer Venus Orbiter, Pioneer Venus Probes (Separate Launch), Vega 1 & 2, Magellan, Venus Express
- Mars (19), Mariner 4, 6, 7 & 9, Viking 1 & 2, Pathfinder, MERs 1 & 2, Phoenix, Mars 2 & 3, MGS, MO, MRO, Mars Express, MSL, MAVEN, MOM
- Jupiter (2), Pioneer 10 & Galileo (Juno will arrive 2016)
- Saturn (1), Cassini
- Jupiter & Saturn (2), Pioneer 11 & Voyager 1
- Jupiter, Saturn, Uranus & Neptune (1), Voyager 2
- Note: Pluto (1) New Horizons arrived July 2015